Earthworms, Soil Fertility and Plant Growth

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INTRODUCTION

Ever since the publication of Charles Darwin's classic book "The Formation of Vegetable Mould through the Action of Worms" (1881): the importance of earthworms in improving soil structure and fertility has been realised, and evidence has been accumulating on the various contributions that earthworms make towards the maintaining soil structure and making it more fertile. Nevertheless, we still lack some fundamental information on the range of activities of earthworms in soil and the mechanisms by which they improve fertility. The aim of this paper is to review the present state of our knowledge and pinpoint areas where further research is necessary. Wherever possible, data from research at Rothamsted, where many important contributions to earthworm research have been made, will be quoted. For a more detailed discussion of some of these points the reader is referred to "The Biology of Earthworms" (Edwards and Lofty 1977).

1. EFFECTS ON SOIL STRUCTURE

Earthworms influence soil structure in a number of ways. They are particularly important in the later stages of soil formation and their main contributions are in the turnover and mixing of soil, the formation of aggregates, improving soil aeration, porosity and drainage and in the breakdown and incorporation of organic matter into soil. It is the last of these roles that has greatest relevance to the theme of this workshop.

1. Soil turnover. During their migrations through the soil earthworms move large quantities of soil; this has been estimated to range from 2 to 250 metric tonnes per ha. annually. The type and placement of cast material differs with the species; some cast large amounts of soil to the surface. Typical of these are *Allolobophora longa* in Europe and *Hyperodrilus africanus* in Africa. Other species line their burrows with cast material or at random in the upper soil layers. An active earthworm population produces a well-broken down and mixed soil in the top 15 to 20 cm. of the soil profile.

2. Formation of aggregates. Aggregates consist of mineral granules linked together into larger and more stable particles.

These can resist wetting, erosion and compaction and contribute considerably to a good soil structure. Soil that has passed through the intestines of earthworms usually contains a higher proportion of aggregates than before ingestion. (Gurianova, 1940; Hopp and Hopkins, 1946; Dawson, 1947; Dutt, 1948; Joachim and Panditesekera, 1948; Chadwick and Bradley, 1948; Swaby, 1949; Bakhtin and Polsky, 1950; Ponomareva, 1950; Teotia et al., 1950; Finck, 1952; Nijhawan and Kanwar, 1952; Mamytov, 1953; Low, 1955; Guild, 1955).

It is not known how earthworms produce these aggregates, but there is evidence that the addition of organic matter to soil can increase the degree of aggregation. (Dutt, 1948; Dawson, 1948; Hoeksema, 1956). It may well be that the association of organic matter with larger microbial populations is the main reason for the increased aggregate formation by earthworms in soils with much organic matter. We need more information on the role of earthworms in the formation of aggregates in the presence of different forms of organic matter, but there is already sufficient evidence to show that the addition of organic matter to soils in the form of animal or human wastes helps to improve the degree of aggregation and hence soil structure and stability.

3. Soil aeration. As earthworms burrow through soil there tends to be an increase in the macroporosity of the soil and this is usually associated with increases in the air volume in soil. (Wöllny, 1980; Stöckli, 1928; Evans, 1948). This is an important factor in determining whether the breakdown of organic matter is aerobic or anaerobic.

4. Soil porosity and drainage. There have been many reports of increases in soil porosity and drainage due to earthworm activity (Stöckli, 1949; Hopp and Slater, 1949; Teotia, 1950; Guild, 1952). Not only do soils with earthworms drain more freely, but also capillary water tends to be retained better and there have been reports of earthworms activity increasing the field capacity of soils. (Guild, 1955; Stockdill and Cossens, 1955; Peterson and Dixon, 1971; Wilkinson, 1975).

5. Breakdown and incorporation of organic matter into soil. Many species of earthworms are favoured by the presence of organic matter. Some species, particularly *Lumbricus terrestris* take organic matter from the soil surface fragment it and pull it down into their burrows. Dead leaf litter is removed rapidly from the soil surface and incorporated into the soil. In England, it has been calculated that up to 90% of the annual leaf fall in orchards is removed from the surface in this way (Raw, 1962). Earthworms can consume and incorporate into soil considerable amounts of organic matter. Even soil-inhabiting species can consume as much as 40 mg per gram of body weight per day. (Barley, 1961). Such movement of organic matter is particularly important in natural habitats, particularly woodlands, in orchards and, more recently, in agricultural soils that are under a zero or minimal tillage

system. Their activity is also increasingly important in arable soils to which have been added, as is increasingly common, animal or human wastes.

In tropical forests, earthworms, can incorporate up to 15 metric tonnes per ha. into soil, i.e. a large proportion of the annual leaf fall. Soils poor in earthworms often have a mat of undecomposed organic matter at the soil surface. (mor soils).

2. EFFECTS OF EARTHWORMS ON PLANT GROWTH

There is a very considerable body of evidence in the scientific literature to show that earthworm activity in soil favours plant growth. They do this by providing channels ideal for root growth and increasing the availability of nutrients, as well as by improving soil drainage and aeration. It is difficult to separate the relative contributions of these different factors in improving soil fertility.

The growth of many crops has been increased experimentally by the addition of earthworms to soils that have low natural populations. Some of these data are summarized in Table 1.

TABLE 1 Effects of earthworms on crop yields

Crop	Yield Increase	Reference
Beans	291%	Hopp and Slater (1949)
Peas	70%	Kahsnitz (1962)
Rye	41%	Russell (1910)
Oats	9%	Aldag and Graff, (1979)
Barley	4.4–201%	Atlavinyte (1968, 1971, 1974)
Barley	3.5%	Edwards and Lofty (1980)
Wheat	14%	Hopp and Slater (1949)
Wheat	300%	van Rhee (1965)
Wheat	2.8%	Russell (1910)
Wheat	2.3–22.0%	Edwards and Lofty (1980)
Rye Grass	100%	Waters (1951)
Grass	73%	Stockdill (1959)
Grass	28–100%	Stockdill and Cossens (1966)
Grass	500%	van Rhee (1965)
Tree Seedlings	26–37%	Zrazhevski (1957)
Spruce Seedlings	15%	Marshall (1970)
Apple trees	2–5%	van Rhee (1970)

Most workers have achieved yield increases by adding earthworms to soils in numbers approximating to average populations (Russell, 1910; Dreidax, 1931; Hopp and Slater, 1949; Uhlen, 1953; Aldag and Graff, 1974). However, a few workers have increased plant growth only by adding above-average numbers of earthworms to the soil (Kahsnitz, 1962; van Rhee, 1965; Atlavinyte, 1968; et al., 1968).

More recently, Edwards and Lofty, (1978) have shown in the laboratory that if intact profiles ot soil that had a low natural population of earthworms and had been continuously direct-drilled (zero cultivation) with cereals for five years, were sterilized and then inoculated with average populations of different species of earthworms, the growth of roots and shoots of barley were greatly increased. Moreover, the maximum root growth was correlated closely with the zone of activity of the earthworms, the shallow-working species promoting root growth in the upper 15 cm of soil and the deep-burrowing species encouraging the growth of deep roots.

Similar experiments which involved the inoculation of average populations of earthworms into five different field soils that had been direct-drilled for more than five years, showed significantly increased root growth and yield of cereals in all experiments. (Edwards and Lofty, 1979, 1980).

Some of the more spectacular results of experiments investigating the effects of earthworms on plant growth have been in New Zealand. The species used was Allolobophora caliginosa and in each field, that had a poor natural population of earthworms, 25 individuals of this species were released. Within four years the earthworms had spread several metres and after eight years, yield increases resulting from the earthworm inoculations ranged from 28% to 110% (Nielson, 1953; Waters, 1955; Barley, 1961; Stockdill and Cossens, 1966).

There have even been reports of earthworms influencing the growth of tree seedlings (Zruzhevski, 1957; Marshall, 1971), and apple trees (van Rhee, 1971).

a) Promotion of root growth by provision of channels. Several workers have suggested that earthworm burrows provide ideal channels for the growth of plant roots (Ellis et al, 1977; Cannell and Finney, 1973; Scott Russell *et al*, 1975). However, there has been little experimental evidence for this until Edwards and Lofty (1980) demonstrated experimentally that cereal roots would follow channels made either by earthworms or artificial channels resembling those that earthworms produce. Workers at East Malling Research Station have produced a time-lapse film which showed roots moving through the soil to follow earthworm burrows or similar channels.

b) Improved root growth through great availability of nutrients. It is now well established that earthworm casts contain more available mineral nutrients than the soil in which the worms live. In particular, they have a higher base-exchange capacity, and more exchangeable calcium, magnesium and potassium and available phosphorus than soils without earthworms. (Table 2). (Powers and Bollen, 1935; Puh, 1941; Lunt and Jacobson, 1944; Stöckli, 1949; Ponomareva, 1950; Finck, 1952; Nye, 1955; Czerwinski et al, 1974).

The mechanisms by which earthworms increase the availability of mineral elements for plant growth are still unknown but it seems likely that it is a feature of microbial activity in the earthworm gut. There is some evidence that calcium is actively excreted. (Robertson, 1936). Some workers have speculated that it is the selective feeding by earthworms that increases the nutrients in the casts.

TABLE 2 Influence of earthworms on the availability of mineral nutrients in soil.

Nutrient		Lunt and Jacobson 1944	Graff 1971	Puh 1941	Nielson
Organic	W	5.17	8.55	1.52	–
Carbon	–	0.24	3.92	1.20	–
Total	W	0.35*	0.54	0.15	–
Nitrogen	–	0.24	0.35	0.05	–
Total	W	1.19	–	2.37	2.8
Calcium %	–	0.88	–	1.95	2.4
Exchangeable	W	2793	–	–	–
Calcium (ppm)	–	1993	–	–	–
Total	W	0.54	–	–	–
Magnesium %	–	0.51	–	–	–
Exchangeable	W	492	–	–	–
Magnesium	–	162	–	–	–
Total	W	150	137	54	90
Phosphorus (ppm)	–	21	22	37	40
Total	W	358	446	294	high
Potassium (ppm)	–	32	70	193	low
pH	W	7.0	5.8	6.8	6.3
	–	6.4	5.0	6.2	6.0

W = worm casts — = soil * Nitrate N was 21.9 ppm for casts and 4.7 ppm for soil.

c) Effects on pest and disease problems. The interactions between earthworms and disease producing organisms have been very poorly studied. It has been speculated that they can disperse the infective stages of certain fungal diseases such as 'dwarf bunt' (*Tilletia controversa*) and 'take-all' (*Ophiobolus graminis*) through soil, but the evidence is poor and it is also possible that spores lose their infectivity during passage through the earthworm gut.

There is some evidence of beneficial effects of earthworms on plant diseases. For instance, apple scab (*Venturia inaequalis*) overwinters as perithecia on fallen apple leaves on the soil surface. A good earthworm population (especially of *Lumbricus terrestris*) can remove practically all the annual leaf fall during winter and prevent carry-over of the disease (Figure 1). Similarly, a species of leaf miner (*Lithocolletis blancardella*) which overwinters on leaves can be controlled by earthworms (Mills, 1976).

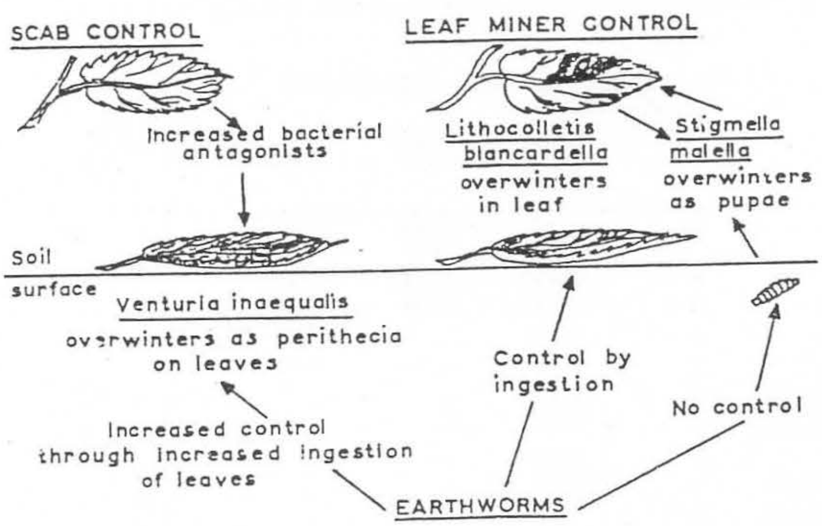

FIGURE 1. Interactions between earthworms and pests and diseases (Mills, 1970).

3. SOIL IMPROVEMENT WITH EARTHWORMS

Since it seems well-established that earthworms can improve soil fertility, there has been considerable interest in the improvement of poor soils, mining spoils and reclaimed land, by inoculating or encouraging the build-up of earthworm populations. There have been many attempts to do this on a large and a small scale and the attempts have achieved mixed results. The failures are probably due to a lack of fundamental knowledge on the environmental

requirements and ecology of many species of earthworms and also to the use of unsuitable species. Many studies have involved breeding of large numbers of *Eisenia foetida* for inoculation into poor soils and this species does not do well in soil and has very limited effects on soil structure or fertility.

a) Reclaimed flooded land. Some of the most promising studies have been in the use of earthworms to accelerate the development of polders and flooded areas in the Netherlands that have been reclaimed with the aim of putting them into cultivation. Inoculation of reclaimed polders with *A. caliginosa* and *L. terrestris* has resulted in rapid colonization in three to four years and increased growth of the roots of fruit trees grown in the inoculated soils (van Rhee, 1969; 1971).

b) Opencast mining sites. When opencast mining sites are covered with top soil with the aim of revegetating them, the growth of plants is often slow. Several workers have studied the rate of recolonization of such soils by earthworms (Dunger, 1964, 1968; Hutson, 1974). There has been much speculation as to the possibility of accelerating the revegetation by introduction and encouragement of earthworms. In one site in the United States of America, revegetated with black locust (*Robinia pseudoacacia*) and inoculated with earthworms, they buried or consumed a 60 mm thick layer of litter in 174 days and greatly improved soil structure (Vimmerstedt and Finney, 1973). In another study on reafforestation of spoil banks, a few *L. terrestris* released rapidly colonized the site and accelerated organic matter breakdown. Current work at Rothamsted is investigating inoculating earthworms into reclaimed strip mine sites after addition of animal or human wastes.

c) Grassland and moorland improvement. Most of the studies into the improvement of grassland by inoculation and encouragement of earthworm populations have been in New Zealand. Several workers have introduced *Allolobophora caliginosa* into grassland which has a poor native earthworm population and followed the build-up in numbers and the effects on growth and yield (Hamblyn and Dingwell, 1954; Nielson, 1955; Stockdill, 1959; Bailey, 1961; Barley and Kleinig, 1964; Kleinig, 1966; Stockdill and Cossens, 1966). The improvement was accelerated by the addition of about one ton of lime per acre. It seems probable that many marginal pastures and moorland could be improved by increased earthworm populations and there would seem to be a good potential for disposal of animal waste material on grassland because this has been shown to build up earthworm populations (Cotton and Curry, 1980; Curry, 1976). Where required, such a programme could be combined with inoculation of earthworms into sites with an impoverished natural earthworm fauna.

4. A PROGRAMME FOR BUILDING UP LARGE EARTHWORM POPULATIONS IN AGRICULTURAL LAND

There is good evidence that earthworms improve fertility (as discussed in Section 2). Thus, particularly in land with minimal tillage, there are good reasons for maintaining large earthworm populations and activity. We have had a long-term programme at Rothamsted investigating the effects of different agricultural practices on earthworm populations. These include studies into the effects of factors such as cultivations, burning straw, pH amendment, the use of pesticides and fertilizers and, in particular, the addition of organic matter to agricultural soils. The aim of these studies is to assess their relative importance so that a model 'earthworm management' programme can be developed.

a) Cultivations

There have been many reports in the literature of cultivations decreasing earthworm populations but there is some evidence that one or two light cultivations have little effect on earthworms and can favour earthworm activity and may even increase numbers temporarily (Hopp and Hopkins, 1946; Zicsi, 1969; Edwards and Lofty, 1970, 1977). However, repeated cultivations over a number of years tend to decrease earthworm populations (Graff, 1953; Edwards and Lofty, 1971). There is some evidence that this effect is caused less by mechanical damage, or bringing the earthworms to the surface where they can be preyed upon by birds, but rather due to the gradual decrease in organic matter status in land that is continually cultivated (Evans and Guild, 1948; Edwards and Lofty, 1977). Evidence in support of this has been provided when the effects of mulching with the remains of the previous crop, to provide an insulating layer and a source of organic matter, have been studied (Hopp, 1946; Hopp and Hopkins, 1946; Slater and Hopp, 1947; Teotia et al, 1950; McCalla, 1953).

More recently, with the advent of minimal cultivation and zero tillage or direct drilling, which involves killing the existing crop with a herbicide and then reseeding a new crop with a special seed drill, it has been shown that large populations of earthworms can build up even in regularly-cropped land (Figure 2). (Edwards and Lofty, 1975a, 1975b, 1975c; Gerard and Hay, 1979; Barnes and Ellis, 1980). Some recent work at Rothamsted has shown that after five years of repeated direct drilling populations of Lumbricus terrestris and Allolobophora longa could build up to as much as 30 times those in regularly cultivated soils.

b) Addition of organic matter

It has long been known that soils to which farmyard manure has been added have larger populations of earthworms (Morris, 1922, 1927; Doekson, 1959; Satchell, 1955; Edwards and Lofty, 1975). (Table 3).

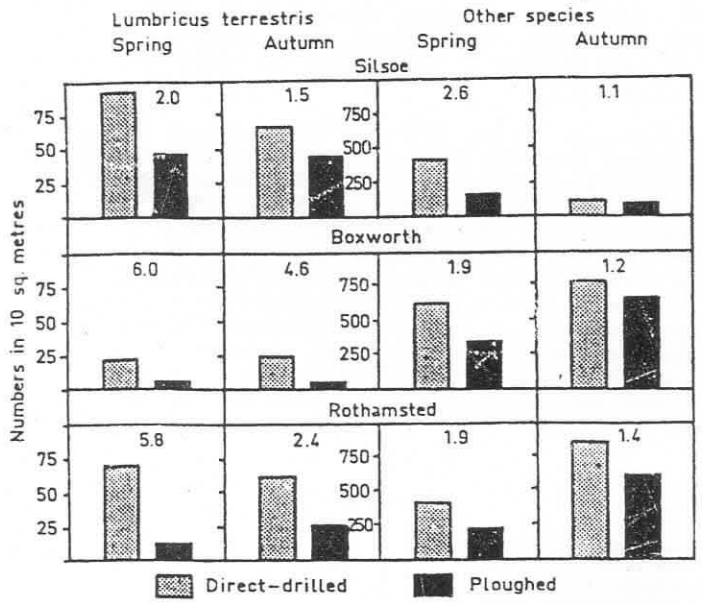

FIGURE 2 Populations of earthworms in relation to cultivation.

TABLE 3 Earthworm populations in the Park Grass Experiment at Rothamsted (after 118 years)

Plot No.	Treatment	pH	A.nocturna	A.caliginosa	A.rosea	O.cyaneum	L.terrestris	Total Number	Weight L.terrestris (gm)	Weight Other spp. (gm)	Total Weight (gm)
2a 2b	Control	5.2	0	1	7	2	99	111	106	4	110
2c 2d	No organic matter	7.2	2	9	42	27	52	133	96	30	126
13a 13b	Farmyard Manure (4 ton/acre)	5.3	65	22	22	3	140	159	230	99	329
13c 13d	plus Fishmeal (6 cwt/acre)	7.0	111	45	15	67	153	359	248	218	566

From: Edwards and Lofty (1975)

More recently it has been shown that other forms of organic matter such as cow slurry (Pain, 1974), pig slurry (Curry, 1976; Cotton and Curry, 1980a, 1980b), waste water (Dindal et al, 1978) and sewage cake (Edwards and Lofty, unpublished), also greatly increase populations of most species of earthworms when applied to agricultural soils. (Table 4).

As methods of disposal of animal and human waste become more limited and restrictive, ever-increasing quantities of such waste materials are being disposed of on agricultural land, because they increase crop growth very considerably at low cost, other than that of transporting the materials from intensive animal units or sewage farms. When this is done, the earthworms are extremely important in helping to breakdown this organic material and thoroughly mix it into the soil. There is good evidence, as discussed earlier, that earthworms make mineral nutrients contained in the organic matter, available much more quickly. Thus, the organic matter encourages build-up of large earthworm populations and reciprocally, the earthworms dispose of the organic matter and make its nutrients available to plants.

TABLE 4 Earthworms and Organic Matter
Numbers and Weight Per 4 m^2

	Treatments	L.terrestris	A.longa	A.caliginosa	A.chlorotica	TOTAL NUMBER	weight in grams
After 12	NIL	1	0	29	65	95	9.6
months	FYM	4	3	36	140	183	12.6
(Spring)	SEWAGE CAKE	7	0	70	214	291	16.1
After 18	NIL	9	5	176	255	445	57.7
months	FYM	19	11	264	593	887	141.8
(Autumn)	SEWAGE CAKE	11	9	336	876	1232	179.3

FYM = Farmyard Manure   SEWAGE CAKE / FYM } Applied at = rate, 200 Kg/ha Nitrogen

c) Inorganic Fertilizers

Most crops are treated with some form of fertilizer and, at the present time, the greater proportion are treated with inorganic chemicals. There is not much published literature on the effects of inorganic fertilizers on earthworm populations, and some contradictory results have been published, usually because the type of fertilizer applied was not specified or the earthworm species affected was not defined (Uhlen, 1953). It seems that sulphates and phosphates used alone may be detrimental to earthworms particularly in the ammonium form (Richardson, 1938; Jefferson, 1955; Kuhnelt, 1961; Davey, 1963; Rodale, 1961; Edwards and Lofty, 1975, 1977). It seems that other inorganic fertilizers generally favour earthworm populations (Brauns, 1955; Franz, 1957; Ronde, 1959, 1960; Ronde, et al, 1958; Jacob, 1952; Jacob and Wiegand, 1952).

In particular, earthworms populations tend to increase after use of superphosphates (Doerell, 1950; Sears and Evans, 1953), and especially calcium (Edwards and Lofty, 1975, 1977). Large doses of nitrogenous fertilizers tend to favour earthworm populations (Edwards and Lofty, 1975, 1980). (Table 5).

Earthworm populations may be influenced by fertilizers either through chemical changes in soil or by increasing plant production (Jacob, 1952; jacob and Wiegand, 1952).

TABLE 5. Effects of inorganic and organic fertilizers on earthworm populations, Broadbalk, Rothamsted, 1979

Treatments	L.terrestris	A. longa	A.caliginosa	A.chlorotica	Weight L.terr' + A.longa	Weight Others (gm)
FYM + 2N	219	71	81	195	305.6	64.1
FYM only	139	41	147	239	191.7	74.2
* 4N, PK Mg	64	25	36	137	106.6	17.1
* 3N, PK Mg	43	14	36	92	64.3	18.5
* 2N, PK Mg	20	9	29	69	20.1	18.9
* 1N, PK Mg	16	9	11	27	22.9	6.1
PK Mg	24	8	3	11	52.1	1.6
NO FERTILIZER	16	5	3	11	15.1	1.7

FYM = Farmyard Manure

* 4N ≡ 153 Kg/ha
3N ≡ 115 Kg/ha
2N ≡ 77 Kg/ha
1N ≡ 38 Kg/ha

d) Adjustment of pH

Earthworms do not multiply in very acid soils and there is evidence that addition of lime to agricultural soils favours increases in earthworm populations (Richardson, 1938; Crompton, 1953; Jefferson, 1955; Satchell, 1955; Edwards and Lofty, 1975). Most species of earthworms tend to prefer soils with a pH close to 7.0 (Edwards and Lofty, 1977) but some species such as Bimastos eiseni, Dendrobaena octaedra and Dendrobaena rubida are acid-tolerant whereas A. caliginosa, A. nocturna, A. chlorotica, A. longa and A. rosea are much less tolerant of acid conditions (Satchell, 1955). L. terrestris is not very sensitive to pH but is more numerous in soils approaching neutrality. Evidence for this was in a survey of earthworms in the Park Grass Experiment at Rothamsted. (Figure 3).

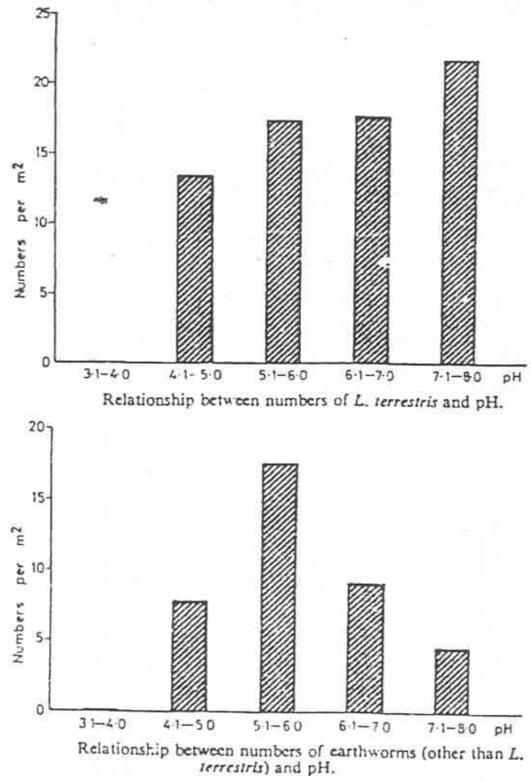

FIGURE 3. Relationships between earthworm numbers and pH Park Grass Experiment (Edwards and Lofty, 1975)

e) Strawburning and disposal

The burning of straw in cereal fields after harvest has been increasingly common in England and, currently, about 50% of fields are burnt in this way. Studies at Rothamsted since 1974 have shown that the effects of strawburning upon earthworms are due more to the removal of the straw which is a source of organic matter for food, than to any direct effects of the burning. So the results of our studies on the effects of strawburning upon earthworms ~~show results that~~ can be used to predict the effects or removal of straw or other crop residues from agricultural fields upon earthworm populations. In our experiments (Figure 4) the effects of burning straw were much greater on the deep-burrowing L. terrestris than on any other species (Edwards and Lofty, 1979 a and b).

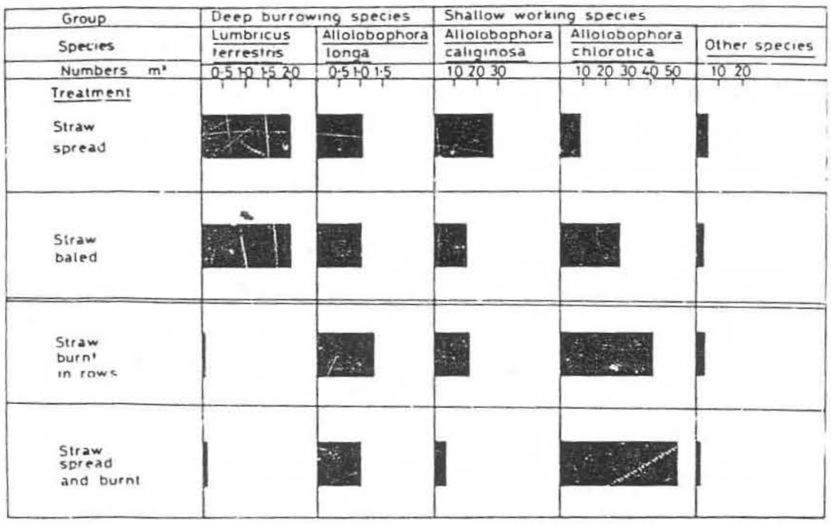

FIGURE 4. The effects of burning straw for three consecutive years on earthworm populations.

f) The effect of crop rotations on earthworm populations.

Compared with other factors that affect earthworm populations, much less is known about the influence of different crop rotations. It is well established that grassland can support more earthworms than land under arable crops (Hopp and Hopkins, 1946; Ponomareva, 1950; Barley, 1959).

It has been reported from the United States that earthworm populations were smallest under row crops and greatest under winter cereals and summer legumes (Hopp, 1946); the more frequently row crops were grown the smaller were the earthworm populations reported. In other studies, the lowest earthworm populations occurred under continuous corn, rather more under continuous soybeans and largest under continuous winter cereals (Hopp, 1946). These findings were substantiated when a 'classical' experiment in Broadbalk field at Rothamsted that had grown wheat either continuously or in rotations for 136 years was sampled in 1979. (Table 6).

TABLE 6. Populations of earthworms under different rotations in Broadbalk, Rothamsted, 1979.
(Earthworms in 4 m^2)

Previous Crop	Crop at Sampling	L. terrestris	A. longa	A. caliginosa	A. chlorotica	Total No Worms	Total weight Worms (gms)
Beans, Wheat	Fallow	NIL	NIL	NIL	NIL	NIL	NIL
Wheat, wheat	Fallow	NIL	NIL	NIL	NIL	NIL	NIL
Wheat, Potatoes	Potatoes	NIL	NIL	NIL	NIL	NIL	NIL
Potatoes, Beans	Wheat	30	4	6	70	110	63.9
Continuous wheat	Wheat	48	19	27	103	197	116.3

Manurial treatment: 4N, PK, Mg (4N = 153 kg/ha)

The continuous wheat supported many more earthworms than any of the normal rotations.

More information is needed on how crops interact with earthworm populations and which species of earthworms are the most important.

g) The influence of pesticides upon earthworm populations

The amounts and variety of pesticides used regularly on agricultural land are continuously increasing. Many of these, although designed to kill arthropods, are also toxic to earthworms. Some of the older compounds used before the Second World War such as arsenic compounds, and copper compounds, particularly copper sulphate are very toxic to earthworms (Davey, 1963; Edwards and Thompson, 1973; Raw and Lofty, 1959).

During the last 20 years, the toxicity to earthworms of most pesticides that are likely to reach soil has been assessed in a long-term laboratory and field testing programme at Rothamsted. (Edwards and Thompson, 1973; Edwards and Lofty, 1977). Some of the results expressed on an empirical scale of toxicity are summarized in Figure 5.

The pesticides that are most toxic to earthworms are the fumigant nematicides, chlordane and endrin, phorate and virtually all carbamate pesticides, particularly the carbendazim fungicides (Edwards and Lofty, 1977).

Earthworms also take up pesticide residues into their tissues, Those most readily taken up are organochlorines and pesticides containing heavy metals. To maintain earthworm populations in agricultural land at as high a level as possible, it is important to minimize the use of harmful pesticides. Particular problems are caused by the carbendazim fungicides such as benomyl which are being increasingly used on cereal crops and in orchards.

Earthworms are considered important enough animals to be designated as key indicator organisms for assessment of soil pollution by pesticides and industrial chemicals (Edwards, 1978, 1980). Such toxicity data will be required by organizations such as the European Economic Community (E.E.C.) and the Organization for Economic Cooperation and Development (O.E.C.D.).

We have adequate information on the effects of pesticides on earthworms to feed into an earthworm management programme.

h) Earthworm management programme

The aim of such a programme would be to bring together data on the relative importance of the overall effects of the various agricultural practices discussed earlier in this section and evaluate them. The inputs to such a system are summarized in the model given in Figure 6.

We still need more data on the relative impact of some of the factors before we can construct a meaningful simulation model. However, data are being accumulated rapidly and it should be feasible to put together a suitable programme to ensure a large earthworm population in most soils. There are constraints on such a

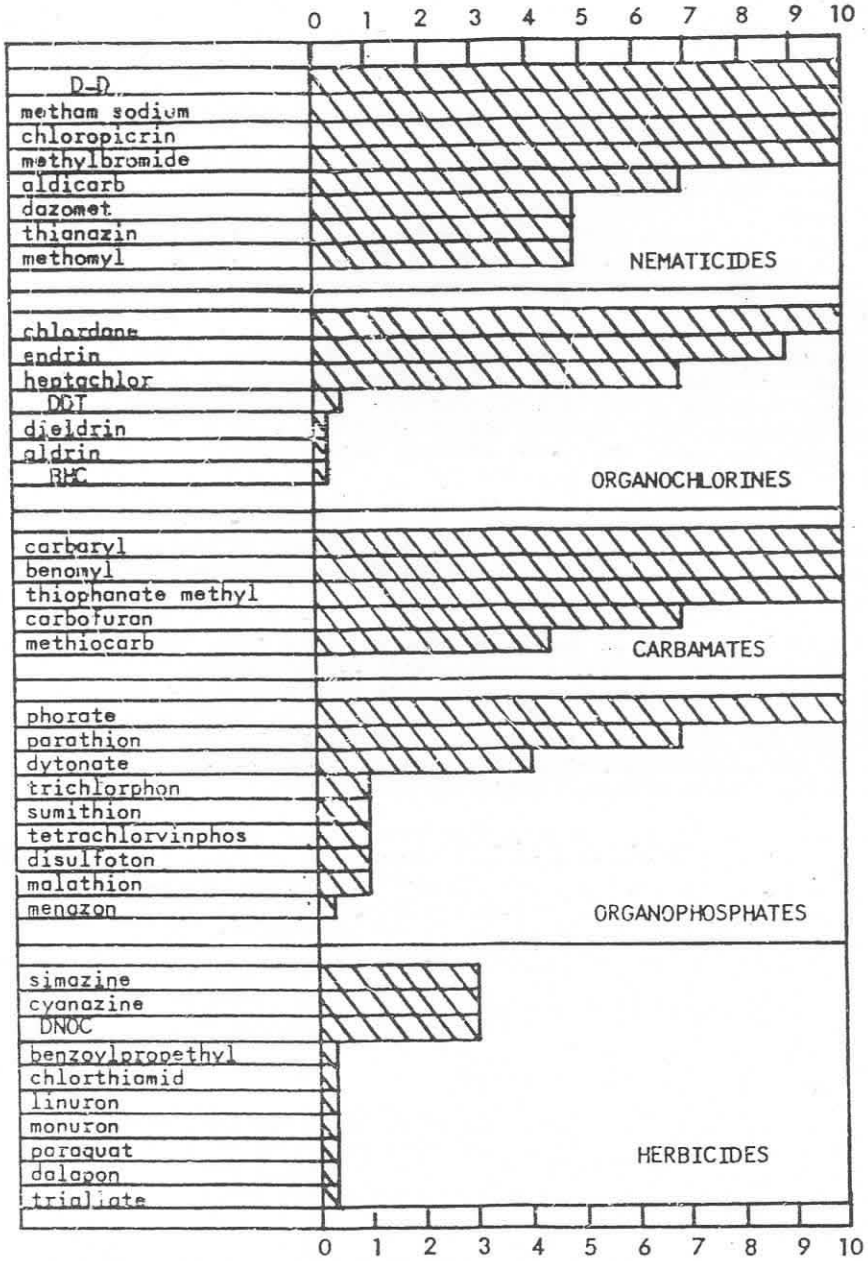

FIGURE 5. Empirical representation of toxicity of pesticides to earthworms.

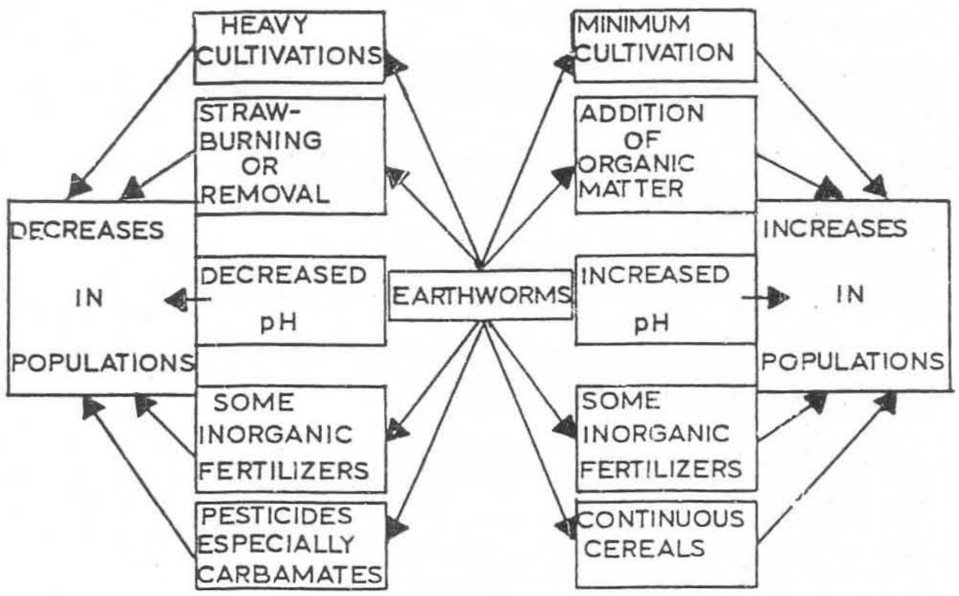

FIGURE 6. An earthworm management programme

programme in economic terms, because practices which themselves ensure a higher yield may override any measures necessary to build up earthworm populations. Thus, it seems likely that any programme will have to take account of all practices and be a compromise of using all measures that favour earthworms in the context of practical farming.

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